Epicardial Electrocardiograms Recorded in the Course of Seven Cases of Heart Surgery

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Thirty-eight direct electrocardiographic records have been obtained by applying an exploring electrode directly to the epicardium after incision of the pericardium in the case of seven patients subjected to thoracotomy for various forms of heart surgery. These cases include three individuals with the tetralogy of Fallot, one with mitral stenosis, one with coarctation of the aorta, one with probable pulmonary atresia and one with a patent ductus arteriosus. This exploration has permitted us to study the patterns obtained in different regions of the right and left ventricular epicardial surfaces in four patients with right ventricular hypertrophy, two patients with left ventricular hypertrophy, and one patient with a heart whose left ventricle-right ventricle ratio was probably little disturbed.

It is now well recognized that certain characteristic modifications of the QRS complex in unipolar precordial leads will result from right or left ventricular hypertrophy, respectively. However, there have not yet appeared any reports concerning the form of QRS in direct epicardial leads in such cases in man. Recently, we were afforded an opportunity to obtain such information in four instances of right ventricular hypertrophy (three due to tetralogy of Fallot and one to mitral stenosis) and in two instances of left ventricular hypertrophy (one due to a coarctation of the aorta and one due to an obscure type of anomaly associated with pulmonary atresia). In the present communication, it is our purpose to describe the findings thus obtained and to correlate the QRS pattern in direct epicardial leads with that in unipolar precordial leads in right and left ventricular hypertrophy, respectively.

**Method**

After the heart was exposed and the pericardium incised during operation for the treatment of the cardiovascular anomalies already described, direct unipolar leads were obtained by the application of an electrode directly upon various sites on the ventricular epicardium. The type of electrocardiograph available at the time of these studies did not permit the simultaneous registration of a lead on the body surface. The instrument was standardized to one-half of the usual sensitivity. The exploring electrode consisted of a polished silver disk measuring 13 mm. in diameter and 1 mm. in thickness. To one edge was attached a long handle, which facilitated its application. The disk was pliable and could be bent easily and made to conform to the cardiac surface being explored. This electrode could be introduced easily through the rent in the pericardium and could be held in contact with the visceral epicardium without the aid of absorbent cotton or other substance. The sites selected for the application of the exploring electrode were noted and charted, so that appropriate correlations could be made. Comparisons were then made in the same

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***Fig. 1.*** A comparison of the QRS pattern in conventional unipolar precordial leads with that in direct unipolar epicardial leads in a patient with tetralogy of Fallot, who had considerable right ventricular hypertrophy. The curves in C constitute the records obtained with the electrode in contact with the right auricular and right ventricular epicardium at the various indicated sites. The curves in D constitute the records obtained with the electrode in contact with the left ventricular epicardium at the various indicated sites over that chamber. The number over each tracing corresponds to the respective site, and so identifies the location of the exploring electrode. (The findings are explained in the text). Note in particular that a direct lead from high on the right auricle shows a Qr pattern and that direct leads from the right ventricular epicardium are characterized by a large R wave, a late intrinsicoid deflection (0.09 second at point 3), and an absence of a Q wave. By contrast, the direct leads from the left ventricular epicardium are characterized by a large R wave preceded by a Q wave, a relatively unimpressive S wave, except when the electrode is in contact with the posterior wall of the left ventricle, and an intrinsicoid deflection that is not late (0.04 second at points 5, 7, and 8). The fact that a Q-S pattern preceded by a purely positive auricular deflection was recorded at point 6 suggests that this point was probably near the auriculoventricular junction.
2. Right ventricle, anterior wall. 3. Right ventricle, anterior wall, close to right border. 4. Right ventricle, right border. 5. Left border of the heart, near the apex. 6. Left ventricle, higher part of the posterior auriculoventricular groove. 7. Left ventricle, posterior wall. 8. Left ventricle, posterior wall.

Figure 1.

Fig. 2. A comparison of the QRS pattern in conventional unipolar precordial leads with that in direct unipolar epicardial leads in a patient with tetralogy of Fallot, who had considerable right ventricular hypertrophy. All curves in C and the first of D are the records obtained with the electrode in contact with the right ventricular epicardium at the various designated sites. The remaining curves in D are the records obtained with the electrode in contact with the left ventricular epicardium at the various designated sites over that chamber. The number over each trace corresponds to the respective site and thereby identifies the location of the exploring electrode employed in the deri-
Male aged 7. Tetralogy of Fallot. A, B. Records before operation. C. Epicardial records during operation (June 17, 1950). 1. Right ventricle, right border. 2. Right ventricle, higher part of the anterior wall. 3. Left ventricle, higher part of the posterior wall. 4. Left ventricle, lower part of the left border.

Fig. 3. A comparison of the QRS pattern in conventional unipolar precordial leads with that in direct unipolar epicardial leads in a patient with tetralogy of Fallot, with considerable right ventricular hypertrophy. The first two curves in C comprise the records obtained with the electrode in contact with the right ventricular epicardium at sites 1 and 2, and the last two curves in C are the records obtained with the electrode in contact with the left ventricular epicardium at sites 3 and 4. Note that direct leads from the designated sites of the right ventricular epicardium are characterized by a large R wave, a late intrinsicoid deflection (0.06 second), and an absence of a Q wave. By contrast, the direct leads from the left ventricular epicardium are characterized by a large R wave preceded by a Q wave, a relatively unimpressive S wave, and an intrinsicoid deflection that is not late (0.04 second).

vitation of the lead. (See text.) Except for a lead made with the electrode over the thinner trabecular zone (site 1), direct leads from the right ventricular epicardium are characterized by a large R wave, a late intrinsicoid deflection (0.07 second), and absence of a Q wave. By contrast, the direct leads from the left ventricular epicardium are characterized by a large R wave preceded by a Q wave, a relatively unimpressive S wave, and an intrinsicoid deflection that is not late (0.045 second). In several tracings from both the right and left ventricles, evidence of injury current is seen.

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FIG. 4. All the curves in C and the first in D constitute the records obtained with the electrode in contact with the right auricular and right ventricular epicardium at the various sites; the last two curves in D constitute tracings obtained with the electrode in contact with the left ventricular epicardium. Except for two leads, the first made with the electrode near the interventricular groove (site
Male aged 10. Pulmonary atresia. A, B. Records before operation. C. Epicardial records during operation (June 3, 1950). 1. Anterior wall of the heart near the right auricle. 2. Anterior wall of the heart, higher part. 3. Anterior wall of the heart, middle part. 4. Left ventricle, near the left border. 5. Left ventricle, posterior wall.

Fig. 5. A comparison of the QRS pattern in conventional unipolar precordial leads with that in direct unipolar epicardial leads in a patient with pulmonary atresia with considerable hypertrophy of the left ventricle. All the curves in C comprise the records obtained with the electrode in contact with the left ventricular epicardium at the five corresponding sites. In such direct leads, a large R wave preceded by a Q wave and a late intrinsicoid deflection (0.065 to 0.08 second) are the important findings.

5) and the other near the apex (site 4), direct leads from the right ventricular epicardium are characterized by a large R wave, late intrinsicoid deflection (0.06 second) and absence of a Q wave. By contrast, direct leads from the left ventricular epicardium are characterized by a very large R wave preceded by a Q wave, a small S wave and a slightly delayed intrinsicoid deflection. This slight delay can probably be attributed to a certain degree of left ventricular hypertrophy resulting from an associated mitral insufficiency. Note that the lead made with the electrode over the right auricle shows a qR pattern.

Fig. 6. A comparison of the QRS pattern in conventional unipolar precordial leads with that in direct unipolar epicardial leads in a patient with coarctation of the aorta, who had definite hypertrophy of the left ventricle. The first three curves in C comprise the records obtained with the elec-
Female aged 17. Persistent patency of the ductus arteriosus. A, B. Records before operation. C. Epicardial records during operation (July 31, 1950). I. Left ventricle, near the apex.

Fig. 7. A comparison of the QRS pattern in conventional unipolar precordial leads with that in a single direct unipolar epicardial lead in a patient with persistent ductus arteriosus unassociated with any hypertrophy of either ventricle. The single curve in C is the record obtained with an electrode in contact with the left ventricle at the designated site near the cardiac apex. There is present a dominant R wave preceded by a prominent Q wave. This pattern corresponds essentially to the precordial lead from the left side zone.

electrode in contact with the right ventricular epicardium at the corresponding sites. The last curve in C and the two curves in D are the records obtained with the electrode in contact with the left ventricular epicardium at the corresponding sites. In the direct leads derived from the right ventricular epicardium, a Q wave is lacking, the R wave is not the main deflection, and the intrinsicoid deflection is not late (0.04 to 0.045 second). By contrast, the direct leads from the left ventricular epicardium are characterized by a dominant R wave that is preceded by a Q wave and an intrinsicoid deflection that is late (0.09 second).
subject between the epicardial leads obtained at the
time of operation and multiple unipolar precordial
leads made in accordance with accepted methods,
prior to the performance of the surgical procedure.

RESULTS

The findings in the four cases exhibiting
right ventricular hypertrophy are shown in
figures 1, 2, 3 and 4. In summary they consist of
(a) the presence of a delayed intrinsicoid
deflection in epicardial leads derived from the
right ventricle and an undelayed intrinsicoid
deflection in epicardial leads derived from the
left ventricle; (b) absence of a Q wave in epicardial leads derived from the right ventricle
and the presence of a Q wave in epicardial leads of the left ventricle; (c) the presence of a
dominant R wave in epicardial leads derived
from the right as well as from the left ventricle;
(d) the presence of an RS or rS type of QRS
in epicardial leads derived from certain selected
sites on the right ventricular surface; (e) the
presence of an qR pattern in epicardial leads
derived from the right auricle; (f) good cor-
respondence between right-sided precordial
leads and right ventricular epicardial leads;
and (g) usual lack of correspondence between
left-sided precordial leads and left ventricular
epicardial leads.

The findings in the two cases exhibiting
left ventricular hypertrophy are shown in
figures 5 and 6. In summary, they consist of
(a) the presence of a delayed intrinsicoid
deflection in epicardial leads derived from the
left ventricle and undelayed intrinsicoid deflec-
tion in epicardial leads derived from the right
ventricle; (b) the absence of a Q wave in
epicardial leads derived from the right ventricle
and the presence of a Q wave in epicardial leads derived from the left ventricle; (c) the
presence of a dominant R wave in epicardial
leads derived from the left but not from the
right ventricle; (d) good correspondence be-
 tween right-sided precordial leads and right
ventricular epicardial leads; and (e) good cor-
respondence between left-sided precordial
leads and left ventricular epicardial leads
except that the intrinsicoid deflection in a
left ventricular epicardial lead may be delayed
even when it is undelayed in the left-sided
precordial lead.

In the case of the patient with a persistent
ductus arteriosus (fig. 7), unassociated with
any ventricular hypertrophy, the QRS pattern
in a single epicardial lead derived from a point
on the left ventricle close to the cardiac apex
is very similar to that in epicardial leads derived
from the left ventricle in instances of left
ventricular hypertrophy.

DISCUSSION

To our knowledge, there have appeared up
to now five papers concerned with direct
exploration of the cardiac potentials of the
human heart during operations which per-
mitted exposure of the heart and the applica-
tion of electrodes thereto.1, 4-7 However, actual
visceral epicardial leads were obtained in only
two instances, one a case of purulent pericar-
ditis1 and the other a case of constrictive pericarditis.5 So far as we are aware, the
present study is the first to attempt a correla-
tion between direct epicardial leads and uni-
polar precordial leads in instances of ventricu-
lar hypertrophy in man.

In our analysis of the data, we have pur-
posefully confined our observations to the form
of QRS. Although it would have been desirable
to study the pattern of the succeeding ventricu-
lar deflection as well, this proved to be impos-
sible because of the modifications of the S-T
segments in the direct leads which resulted
from the injury currents induced by the phys-
ical contact of the exploring electrode with the
visceral epicardium and by the alterations of
repolarization influenced by variations in
coronary flow and environmental tempera-
ture, which followed as a consequence of
exposure of the heart to the atmosphere.

In the two cases of left ventricular hyper-
trophy, there was fairly good correspondence
between the unipolar precordial leads from the
right- and left-sided chest zones and the direct
epicardial leads from the right and left ven-
tricles, respectively. However, the same cor-
relation was not strictly obtained in the cases
exhibiting right ventricular hypertrophy. In
these cases, precordial leads derived from the
extreme left side of the chest were characterized
by a deep S wave and absence of a Q wave,
whereas the epicardial leads from the surface
of the left ventricle were typical left ventricular
epicardial leads, being characterized by a large
R wave which is preceded by a Q wave. To explain these differences between epicardial and precordial leads in cases exhibiting right ventricular hypertrophy, it can be assumed that during the phase of ventricular depolarization, the electrical field surrounding the heart is dominated by the electrical forces created during depolarization of the thickened right ventricle and that this dominant vector will be represented in contralateral precordial leads by oppositely directed deflections. With this interpretation, which is in accord with the conclusions of Barker and Valencia and Goldberger, the large R wave in a precordial lead from the right-sided zone and the deep S wave in a precordial lead from the left-sided zone are to be considered as electrocardiographic representations, in instances of right ventricular hypertrophy, of the same electrical force, that is, right ventricular potentials. An alternative explanation would be to consider the Rs or rS pattern in left-sided precordial leads to be the result of a precordial electrode “facing” certain specialized zones of the right ventricular surface, epicardial leads from which are characterized by a QRS complex conforming to the Rs or rS type.

Summary

1. For the first time, in man, direct epicardial leads have been obtained in four cases exhibiting right ventricular hypertrophy, in two cases exhibiting left ventricular hypertrophy and in one case without hypertrophy of either chamber.

2. In cases with right ventricular hypertrophy, the QRS complex in right ventricular epicardial leads is characterized by either an R, Rs, RS or rS pattern, depending on the portion of the right ventricular surface which is explored. In these same cases, the QRS complex in left ventricular epicardial leads is characterized by a qRs or qrS pattern.

3. In the cases with left ventricular hypertrophy, the QRS complex in right ventricular epicardial leads is characterized by an rs or RS pattern. In these same cases, the QRS complex in left ventricular epicardial leads is characterized by a qRs or qr pattern.

4. With one exception, there is good correspondence between right-sided precordial leads and right ventricular epicardial leads, as well as between left-sided precordial leads and left ventricular epicardial leads. The exception is the deep S wave in left-sided precordial leads in the cases of right ventricular hypertrophy. The rS or Rs pattern in left-sided precordial leads, in such cases, is attributed to the spatial relationship between the exploring electrode and the portion of the right ventricular epicardium from which QRS is characterized by an rS and RS pattern.

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